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HOT WALL THICKNESS VARIATION
MEASUREMENT SYSTEM

S. J. KRUPSKI

MAY 1979



PRODUCT ASSURANCE DIRECTORATE
WATERVLIET ARSENAL
WATERVLIET, N.Y. 12189

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MATERIALS TESTING TECHNOLOGY PROGRAM (AMS 4931)

Report No.: WVT-QA-7901

Title: Hot Wall Thickness Variation
Measurement System

THIS PROJECT HAS BEEN ACCOMPLISHED AS
PART OF THE US ARMY MATERIALS TESTING
TECHNOLOGY PROGRAM, WHICH HAS FOR ITS
OBJECTIVE THE TIMELY ESTABLISHMENT OF
TESTING TECHNIQUES, PROCEDURES OR
PROTOTYPE EQUIPMENT (IN MECHANICAL,
CHEMICAL, OR NONDESTRUCTIVE TESTING)
TO INSURE EFFICIENT INSPECTION METHODS
FOR MATERIEL/MATERIAL PROCURED OR
MAINTAINED BY AMC.

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ABSTRACT

With the introduction of the rotary forge at the Watervliet Arsenal, a new line of inspection equipment was required. The need to design inspection equipment to measure hot cannon tubes in the "as-forged" condition created gaging problems not often encountered in industry. Forgings must be inspected immediately off the forging machine to monitor uniformity of wall thickness. Any tendency toward excessive wall thickness variation must be detected immediately and corrective measures taken. The rate of forge operation could result in the production of many rejectable tubes if inspection was delayed until the forging cooled. The inspection system required development of a new application technique for ultrasonics. Hydraulic pressure is used to bring transducers in contact with the hot forgings and to establish coupling between the transducer and the forging. Wall thickness measurements are taken simultaneously at four positions around the tube circumference and a wall thickness variation at that cross-section is printed out.

CROSS-REFERENCE DATA

ULTRASONICS
COUPLING
DELAY LINE
ROTARY FORGED CANNON TUBE

ACKNOWLEDGEMENT

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1. INTRODUCTION

In 1975, a rotary forging machine was introduced into the Watervliet Arsenal. This machine was manufactured in Austria by GFM and was the largest of its kind in the world at the time of installation. Cannon tubes from 2.5 inch to 8 inch bores are produced from hollow preforms. The purpose of the rotary forge process is to produce a tube forging with minimal material waste thus providing a finished product at lower costs. A conventional 105MM M68 forging starts out weighing 8400 pounds, a rotary forging starts out at 3000 pounds, both to produce a finished tube weighing 1660 pounds.

2. INSPECTION OF THE FORGING

The rotary forge is numerically controlled and is capable of forging a 105MM M68 gun tube in approximately 11 minutes. At this rate 8 hours production could exceed 30 cannon tubes. Standard inspection equipment used on cannon forgings to measure diameters, straightness and wall thickness must be employed after the forging cools.

Wall thickness of rotary forged cannon tubes is critical. Because the forgings contain minimal excess material, wall thickness must be held uniform. Uniform wall thickness insures even material distribution and sufficient stock for final machining operations. A look at the complete production schedule shows a need to measure wall thickness as soon after the actual forging process as possible.

If a malfunction leads to the production of forgings with non-uniform wall thickness, this condition would not be picked up until the forging had cooled sufficiently to allow for the use of conventional inspection techniques. During the 10 hour period required for the forging to cool to approximately 100°F, 40 more tubes could be produced. These 40 tubes could very possibly have the same unacceptable wall thickness characteristics and could be scrap. A definite need existed to develop a method to inspect forgings for wall thickness immediately off the forge machine in order to monitor the production process and take corrective measures if necessary.

Wall thickness inspection of cannon forgings is normally done using ultrasonics. Transducers are applied to the tube surface by hand. Ultrasonic coupling is established between the transducer and the tube surface by placing a small puddle of oil at each measurement point. In the case of hot cannon forgings, new problems arise. First, the transducers would not withstand contact with this hot material. Application of the transducer by hand would be impractical and dangerous. Also the oil used to establish coupling would burn or evaporate instantly. Obviously a different technique for inspection of wall thickness was necessary.

3. ULTRASONICS ON A HOT TUBE

Several companies that specialize in ultrasonics were contacted and there was general agreement that ultrasonics could be applied in this case but, that such a system would border on the state-of-the-art. A specification was written to define what was required of a system to measure wall thickness variation of cannon tubes immediately off the forge machine.

A request for proposal for a system to inspect these hot forgings was sent to several ultrasonic equipment manufacturers with the only acceptable response coming from Sonic Instruments of Trenton, NJ. Sonic agreed to design a system if testing was accomplished to determine if Sonic's approach to this problem would be successful. Testing was done at the Arsenal using a standard ultrasonic transducer, a water-cooled aluminum delay line and a hand operated arbor press. Sections of actual forgings were heated in a small furnace to approximately 1500°F to simulate temperature of the forgings immediately off the forge machine. Transducers were applied to the test sample under approximately 2000 pounds force to attempt to establish ultrasonic coupling. It was theorized that the deformation of the cannon tube surface at this temperature would be sufficient to establish this coupling. Readings were obtained on a standard readout system with varying degrees of accuracy and repeatability. Alignment of the delay line with the sample centerline and the configuration of the delay line proved critical. Three delay line configurations were tested

to determine which gave the strongest signal and the signal that stood clearly above background reflections.

Aluminum and copper sheets were tested as couplants between the delay line and sample and were found to slightly reduce required pressure. Lead sheets were also tried and reduced required pressure to a very low level. However, lead could be valuable only if measurements were to be taken at a medium temperature as it melts away too quickly at test temperatures. Tests showed coupling by pressure was feasible down to approximately 900°F as long as the delay line was aligned on the forging centerline. Delay line configuration was finalized with the use of a 4 inch spherical radius on the tip. Any reflections from the tip of the delay line should bounce back to the same point and thus give a signal on the ultrasonic oscilloscope readout. Making this signal occur at 4 inches puts it just beyond the maximum thickness to be measured. (See figure 1)

4. SYSTEM DESCRIPTION

The wall thickness variation measurement system consists of a traveling bridge riding on 2 tracks. The bridge supports the measurement transducers and moves over the tube along its length. The bridge is motorized and can be stopped at each measurement interval required.

The gun tube to be inspected is supported on three v-block stands. The position of these supports has been established by engineering to minimize the bending of the forging that may occur. Because the yield strength of these forgings at these high temperatures is substantially reduced, support positions are critical. These supports are repositioned for each different tube forging. (See figure 3)

The moving bridge carries the heart of the inspection system. Four ultrasonic transducers with water-cooled delay lines are mounted 90° apart. Each is controlled by a long stroke hydraulic cylinder which holds the transducer against the forging with a force of approximately 2000 pounds. Mounting the transducers in this way allows for measurement of wall thickness variation at a particular cross-section. Transducers will contact the forging surface at four equally spaced points. (See figure 4) Wall thickness readings are not accurate due to the high temperature and corresponding decreased sound velocity, but constant temperature around the forging at each cross-section inspected assures an accurate wall thickness variation measurement. The temperature

gradient from one end of the tube to the other makes it difficult to get accurate wall thickness readings, but since our main concern is the uniformity of wall thickness we need not make provisions to recalibrate the readout at each temperature.

Transducers on the traveling bridge are connected to readouts in a heat insulated cabinet. Four wall thickness readings are displayed and printed along with their measuring positions. A microprocessor computes the variation between minimum and maximum readings and prints the wall thickness variation. Hydraulic motors move the bridge to the next selected cross-section and the process is repeated.

The entire wall thickness variation measurement system is controlled by the operator from a small console. Controls include start-stop switches for hydraulics and water, grip and release buttons, carriage forward, reverse and stop and a switch for the warning horn for cooling water loss. (See figure 5) In operation the operator pushes a button to move the carriage to the test point on the tube and stop it. When the grip button is pushed the four transducers come in contact with the forging under pressure. The electronics are designed to scan the four transducers to check for the existence of a signal at each point. If a signal exists the four readings are printed and a microprocessor computes the maximum variation which is also printed. If one or more signals are lacking the transducers are released and retracted from the forging. The operator then presses the grip button again and the

process is repeated. Once a reading has been recorded, the operator moves the carriage to the next test position and presses the grip button again. The process is repeated until all required test sections are measured. The operator then has a record of wall thickness variation of the forging 15 minutes after the tube was produced. (See figure 2) Data is available for evaluation to determine if any tendency exists which would lead to production of bad tubes. This measurement system provides the necessary data for making adjustments or the decision to stop the forging process before a large number of unacceptable tubes are produced.

5. TESTING RESULTS:

Following installation of the system preliminary tests were run on a cold cannon tube to verify tube alignment and functionality of all controls. Several adjustments in timing and hydraulic pressures were made. Lead sheets were placed between the delay line and the cold cannon surface to act as coupling. Several small problems in the electronic circuitry were overcome and the system was able to make the required measurements.

Next a hot 105MM M68 forging was loaded into the v-stands of the inspection system. The bridge was moved to the muzzle end of the tube and the grip button pushed. The cylinders moved in, took a reading, printed out and retracted. The bridge was moved to the evacuator zone of the tube and another measurement was made, again successfully. The temperature of each of these areas was measured as 1200°-1400°F. The bridge was then moved to a larger diameter area with substantially greater wall thickness. The grip button was pushed but the system did not see four signals of sufficient strength and was automatically retracted. The grip command was repeated and the oscilloscope displays on the four ultrasonic readouts were studied. Two of the four signals were good but two were not picked up correctly by the automatic gain control (AGC) circuitry. The AGC "window" was adjusted somewhat and on another grip attempt the four signals were sufficient and the readings and variation printed out. The grip procedure was repeated toward the breech end of the forging with good results. The third and

breech end prints were at about 1600-1700°F. The tests showed it to be harder to get readings at the thicker wall thicknesses.

Adjustments on the ultrasonic units were found to be more critical in these areas of greater thickness to outside diameter ratio. This ratio has an effect on how "clean" the returning echo is picked up by the ultrasonic readouts.

At each cross-section of the tube measured the wall thickness readings were high due to the decreased sound velocities at these elevated temperatures. The variations in wall thickness printed out were compared to values obtained the next day on the cold tube and were found to be within the $\pm .03$ of actual variation as required by the specification. (See figure 6).

The evaluation of the testing results was satisfactory and the system was accepted.

6. CONCLUSION

The ability of this inspection system to successfully measure wall thickness variation of hot cannon forgings advances the state-of-the-art of ultrasonic inspection. This system can measure actual wall thickness of hot pieces if the temperature is known and the readouts are calibrated to this temperature. It also measures on an extremely rough surface because the delay lines actually deform the surface slightly. Principles of ultrasonic inspection employed in this system have been proven and can now be employed in industry with greater confidence that such a system will perform its job in a production environment.

7. IMPLEMENTATION

This system now is in operation at the rotary forge site providing valuable information about the wall thickness variation of production forgings immediately after the forging process. This information enables production personnel to closely monitor the uniformity of wall thickness of the forgings and to take any measures necessary to produce good tubes.

Recently efforts have been initiated to connect the wall thickness measurement system directly to the forge by conveyor to further integrate the system into the production line. These efforts will reduce material handling time and cost and aid the Arsenal in providing the highest quality tube forgings with minimal expenditure.

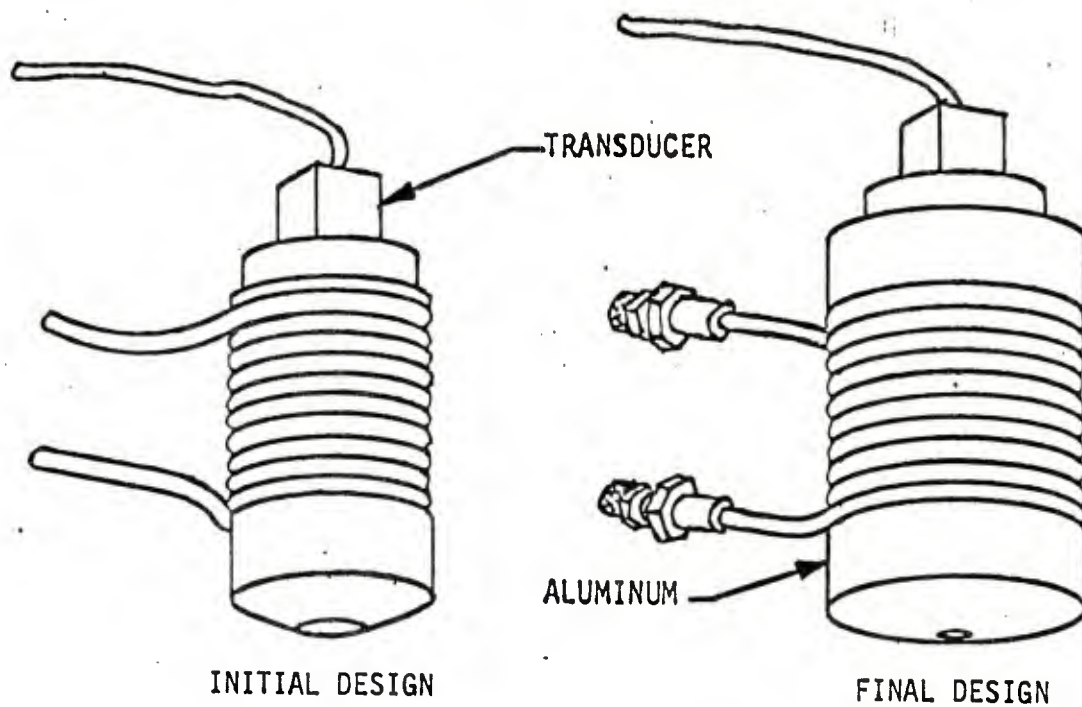


FIGURE 1: DELAY LINE CONFIGURATIONS

POSN 2	4--	0 2.0 5	POSN 4	4--	0 3.4 0
	3	0 2.0 7		3	0 3.4 4
	2--	0 2.0 6		2	0 3.4 7
	1+	0 2.0 8		1+	0 3.4 7
	0	0 0.0 3		0	0 0.0 7
POSN 1	4	0 1.8 7	POSN 3	4--	0 3.4 2
	3--	0 1.8 5		3	0 3.4 5
	2	0 1.8 7		2+	0 3.4 8
	1+	0 1.9 1		1	0 3.4 5
	0	0 0.0 6		0	0 0.0 5

105mm, M68 - MAX ALLOWABLE VARIATION .150

FIGURE 2: SAMPLE READOUT

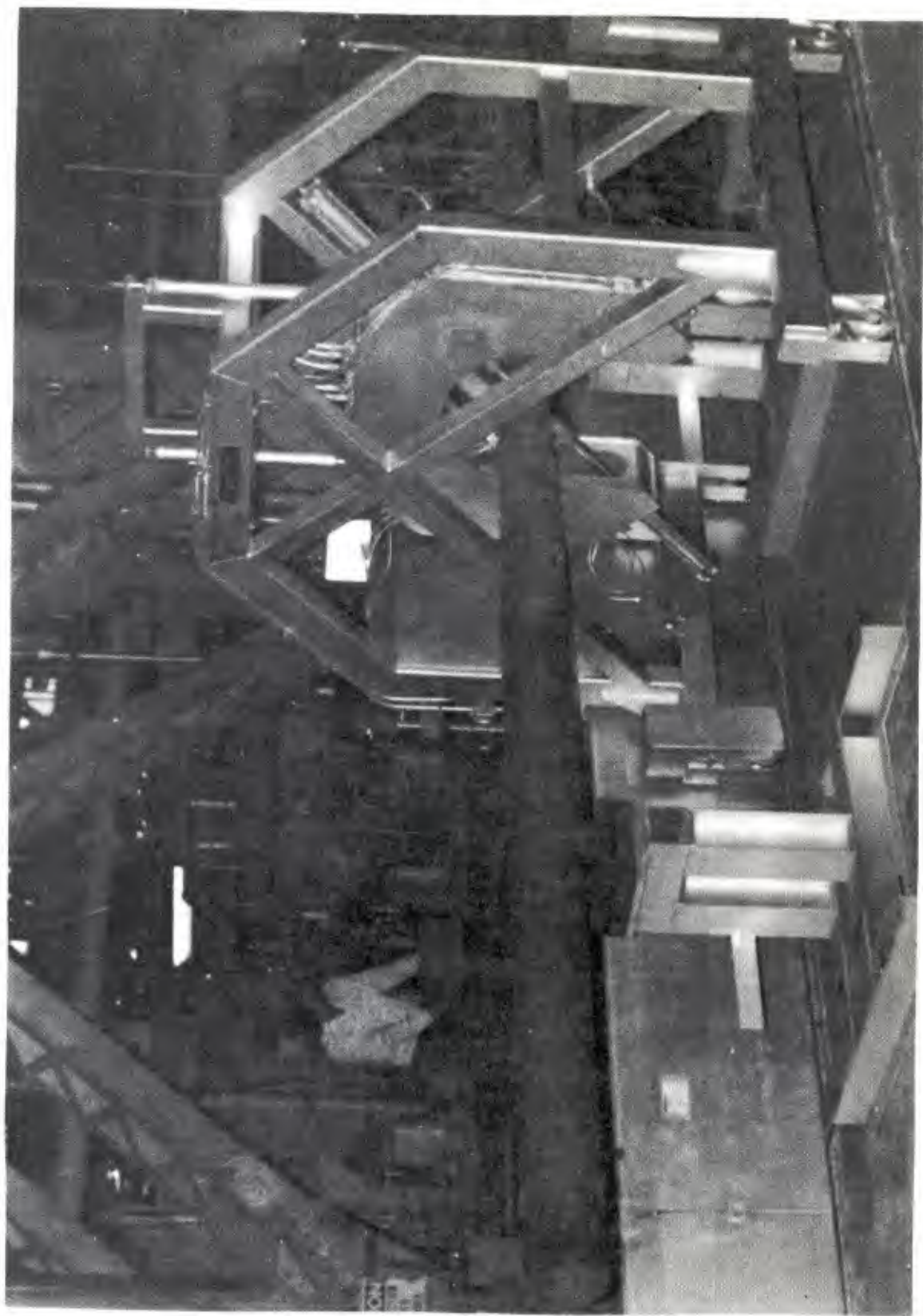


FIGURE 3: HOT FORGING IN INSPECTION STATION

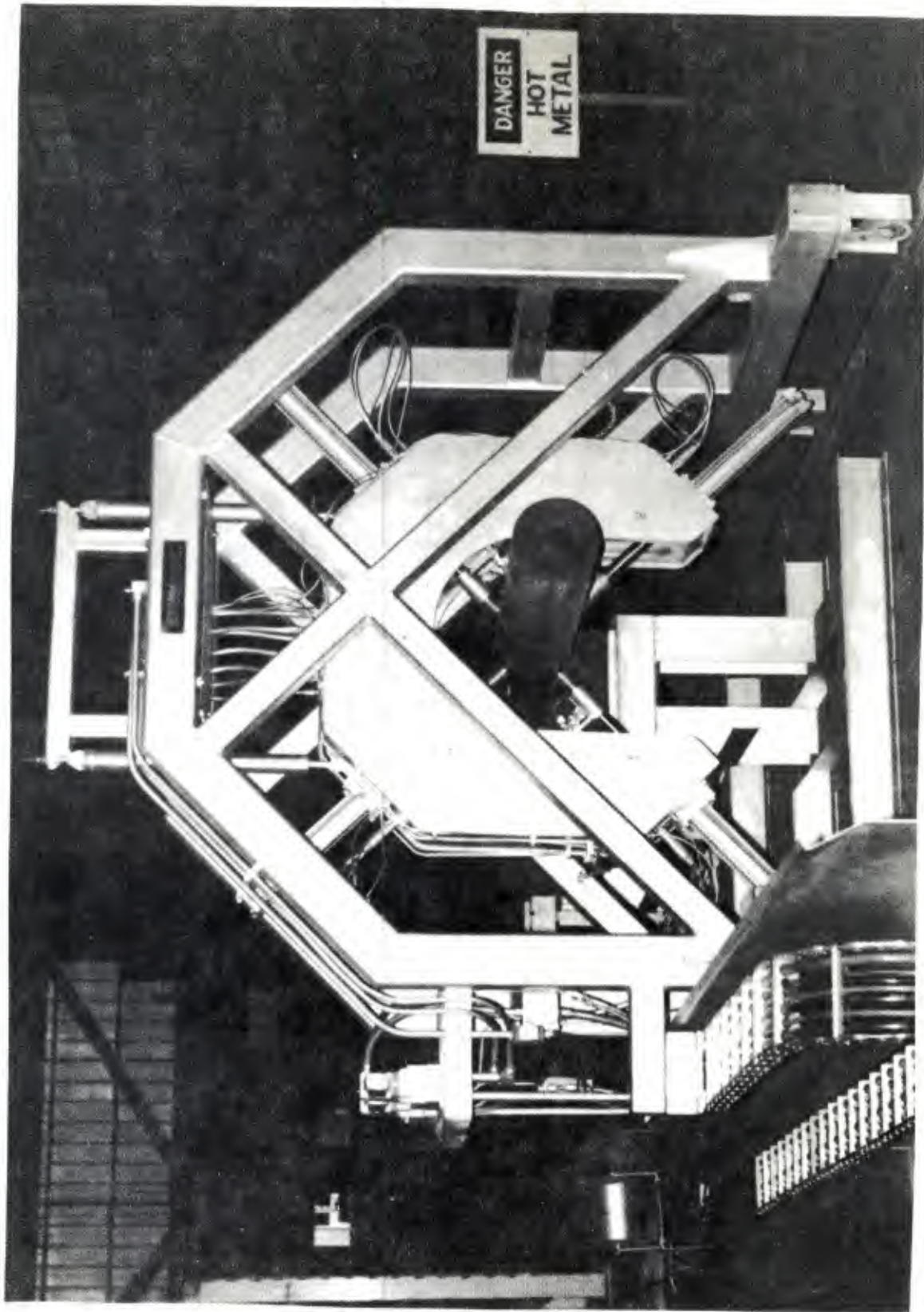


FIGURE 4: TRANSDUCERS CONTACT TUBE

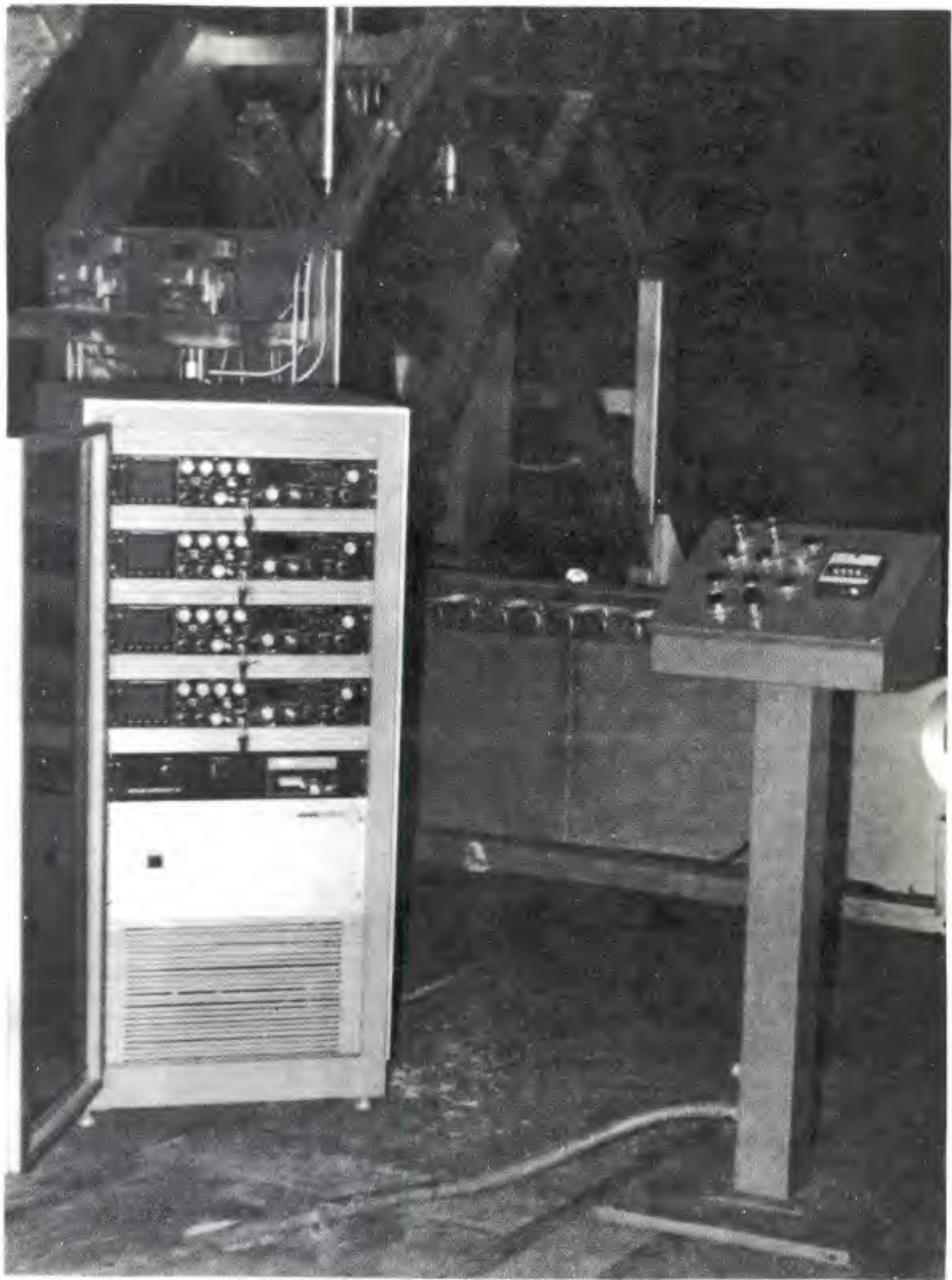


FIGURE 5: CONSOLE AND READOUTS

HOT WALL VARIATION
MEASUREMENT DATA

HOT LOC	(1 MAR 79) MAX VARIATION	COLD MAX VARIATION	(2 MAR 79) (HOT & COLD) DIFF
1	.07	.04	-.03
2	.06	.05	-.01
3	.10	.10	-0-
4	.07	.06	-.01
1	.06	.05	-.01
2	.06	.05	-.01
3	.11	.10	-.01
4	.06	.06	-0-
	AVERAGE	AVERAGE	
1.	.06	.045	-.015
2	.07	.05	-.02
3	.093	.10	+.007
4	.057	.06	+.003

ALL MEASUREMENTS WERE MADE
WITH NO CHANGE OF
VELOCITY SETTING (2320)

FIGURE 6: TESTING RESULTS

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